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Physiological Performance of Soldiers Conducting Long Range Surveillance and Reconnaissance in Hot, Dry Environments

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Combatant Protection and Nutrition Branch
Aeronautical and Maritime Research Laboratory

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ABSTRACT

A study was conducted to investigate the physiological performance of soldiers undertaking long range reconnissance and surveillance activities in the Pilbara region, WA. The results indicated that soldiers experienced very low levels of heat strain during the transport and the setting up of the observation post phases. The heat strain increased to moderate levels while the subjects were conducting a route march in the afternoon. None of the thermal strain indicators (mean core temperature, average heart rate and average area weighted mean skin temperature) exceeded the level considered to indicate moderate heat strain by most civilian OH&S practitioners. The work load on the route march was approximately 50% of the peak metabolic rate, suggesting that this activity was sustainable provided that the environmental heat stress remained moderate. The sweating rate of the soldiers was generally low, with over 90% of the fluid loss attributable to evaporative cooling. There was also evidence that some soldiers experienced hypohydration while one subject appeared hyperhydrated. Based on the outcomes of the Soldier Combat Systems Enhancement Studies and the guidance from DOHSMAN, it is recommended that soldiers undertaking arduous activities should have a minimum fluid intake of 1.5 $L.h^{-1}$ and that an hourly cycle of 30 min work/30 min rest should be introduced if the Wet Bulb Globe Temperature (WBGT) reaches or exceeds 28^{0}C. Caution must be exercised in interpreting the results as the weather conditions at the time of the study were influenced by a low pressure system. Consequently, the study was carried out under conditions far less stressful than normally experienced in this region. It is recommened that a repeat of the study is necessary to ascertain the true levels of heat strain soldiers would experience under typical hot and dry climatic conditions.

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Executive Summary

Military operations in Northern Australia can pose significant physiological challenges to the ADF. The high heat and humidity, the rugged terrain and the enormity of the operational areas are some of the critical factors that can adversely affect the efficiency and effectiveness of operations. There is anecdotal evidence that heat stress is a serious problem in soldiers deployed to the region. The issue can only be resolved by developing effective heat stress management strategies so that troops are better prepared and equipped to deal with the situation. The first step in achieving this objective is by understanding the nature and the severity of the problem, hence the necessity to conduct field studies to evaluate the physiological performance of soldiers undertaking routine training and military operations in the North.

The climatic conditions of the Pilbara region are mostly hot and dry with cyclonic depressions frequently occurring from September to early January. The Army deploys a unit of regimental strength in this region. The Pilbara Regiment is responsible for developing and providing reconnaissance and surveillance capabilities through regular patrols and a network of local observers. Both regular soldiers and reservists are routinely sent to remote areas to conduct surveillance and reconnaissance operations. It is a major concern of the unit that heat stress could cause significant heat casualties, leading to a diminished operational effectiveness.

With the support of the Regiment and Force Development (Land), a field study to evaluate the physiological performance of soldiers undertaking reconnaissance operations in the Pilbara region was conducted over a period of four days. The choice of the study site and the spectrum of activities undertaken by the soldiers were agreed by the Regiment, the investigators and Force Development (Land). The critical physiological variables, including deep body temperature, skin temperature, sweating rate and oxygen consumption were measured while the troops were transported to and from the study site and during their operations. The physical status of the volunteers was determined prior to the commencement of the study to ascertain their suitability for participation. A secondary objective was to evaluate the reliability and suitability of the gastro-intestinal temperature radio pills to measure core temperature under field conditions.

It was unfortunate that the weather conditions were heavily affected by a low pressure system which caused unusually low ambient temperatures, rain and high relative humidity on the first two days of the study. The heavy rain on the second day severely

disrupted the schedule. With the prospect that the study site might become inaccessible, a new venue was chosen for the rest of the exercise. The climatic conditions improved for the final two days.

Results of the study indicate that the soldiers experienced very low levels of heat strain during transport and setting up of the observation post. This increased to moderate levels while subjects were conducting a route march in the afternoon. None of the thermal strain indicators (mean core temperature, average heart rate and average area weighted mean skin temperature) exceeded the level considered to indicate a high degree of thermal strain. The work load imposed by the route march was approximately 50% of the peak metabolic rate, suggesting that the activities were sustainable, provided that the environmental heat stress remained moderate.

The sweating rate of the soldiers was generally low and over 90% of the sweat loss could be attributed to evaporative cooling. There was also evidence that some soldiers suffered from mild hypohydration (insufficient water in the body) while one subject experienced hyperhydration (excessive water in the body). Based on the outcomes of the Soldier Combat Systems Enhancement Studies and the guidance from DOHSMAN, it is recommended that soldiers undertaking arduous activities, such as route march should have a minimum fluid intake of 1.5 $L.h^{-1}$ and that an hourly cycle of 30 min work/30 min rest should be introduced if Wet Bulb Globe Temperature (WBGT) exceeds $28^{0}C$. Caution must be exercised in interpreting the results as the weather conditions at the time of the study were heavily influenced by a low pressure system. Hence this study was carried out under environmental conditions far less stressful than normal. A repeat of the study may be necessary to determine the true levels of physiological strain soldiers would experience under more typical climate conditions in the region.

Authors

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Tony Wai Man Lau graduated with B.Sc (Hons) from the Chinese University of Hong Kong (CUHK), Hong Kong in 1979 majoring in Biology and Biochemistry. He obtained his M. Phil degree in Environmental Biology in 1981. Supported by a Croucher Foundation Scholarship (HK), he studied environmental toxicology at Melbourne University and was awarded a Ph.D. degree in 1987. After a short spell of employment as a senior chemist with the Unipath Pathology Laboratory, he jointed MRL in 1985 and conducted pharmacological studies leading to improved prophylaxis and therapy of nerve agents. He is currently a Senior Research Scientist and Task Manager in environmental physiology. He is also a member of the TTCP HUM TP6 Panel and the Deputy Leader of the Environmental Physiology and Nutrition Focus Area of DSTO's Human Factor Hub .

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Chris Forbes-Ewan graduated BSc (Hons) from ANU in 1972. Trained as a biochemist, he has more than 27 years experience in food science, together with many years of experience in nutritional aspects of physiology. Since 1986 Chris has been Senior Nutritionist at the Defence Nutrition Research Centre. From 1986 to 1994 he led a team that conducted extensive research into food acceptability, food and nutrient intake and energy expenditure. Since 1994, in addition to nutrition research, he has been involved in evaluating the value to the ADF of ergogenic aids (aids to

physical performance). In this time he has also developed new ration scales for the ADF and has conducted research into the effects of heat, humidity and soldier modernisation on hydration status of soldiers.

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1. Introduction

Australian Strategic Policy 98 (1997) has prioritised security requirements for the defence of Australia. Emphasis has been placed on developing appropriate capabilities for sustaining ADF operations in Northern Australia. This area is characterised by sparse population, large deposits of natural resources of strategic value, rugged terrain and tropical climates. The immense area and environmental conditions impose significant challenges to the ADF in conducting operations in the region. It is not uncommon for military personnel to suffer heat strain from a variety of environmental and mission related factors. Through their effects on physical and cognitive performance, debilitating environmental factors such as high temperature and humidity can adversely affect the outcomes of military missions. Exacerbating this are the additional burden of carrying heavy loads over long distances, working in confined and poorly ventilated armoured vehicles and the difficulty in resupplying units on long-range patrols. As a result, heat stress and the resultant debilitation are real threats to soldiers deployed in the North. In Exercise Kangaroo 92, heat stress was a major cause of casualties among soldiers. Anecdotal evidence suggested that more than 20% of hospitalisations at K92 were due to heat illnesses (Amos et al., 1996). Good understanding of the physiological limits under these harsh environments and sound management of heat stress are therefore a prerequisite for effective operations in the North.

Karratha is a regional centre in the Pilbara Region of Western Australia. It is characterised by very hot and dry conditions, e.g. average temperature of 30°C for up to 9 months of the year and a mean annual rainfall of less than 400 mm (Division of National Mapping, 1986). The Army has a surveillance unit of regimental strength located in the region - the Pilbara Regiment which engages in vital assets protection by conducting long range surveillance and reconnaissance operations. A typical operation lasts for one to two days but extended operations of two to three weeks may be required. Most operations involve transporting soldiers by road to a line-up point (LUP). This may be in close vicinity or some distance away from the observation post (OP). In the latter case soldiers must carry substantial loads and walk to the designated site to set up an OP. Exposure to high solar radiation, high temperatures and high levels of physical activity, which together generate a large amount of metabolic heat, may lead to extremely high thermal strain. To develop appropriate heat stress management strategies it is necessary to study the physiological performance of soldiers during missions so that the deleterious effects of local conditions and operational requirements on performance are understood and can be reduced.

With the support of DGLD and LHQ, the Pilbara Regiment agreed to host a physiological performance trial in which the critical physiological variables indicating thermal strain would be monitored under operational conditions. A secondary objective was to evaluate the reliability and applicability of a newly acquired 'radio-pill' for monitoring core body temperature in the field. The trial aimed to establish a baseline understanding of the physiological performance of fully acclimatised soldiers conducting long range reconnaissance and surveillance in hot and dry environments. It

is intended that the database generated will provide guidance leading to an improved plan of heat stress management for the Pilbara Regiment and for other units engaged in similar operations in the same environment

2. Methods

2.1 Subjects

Fourteen soldiers from the Pilbara Regiment volunteered to participate in the trial. Eight subjects were Army reservists while the other six were regular soldiers. The subjects were briefed on the objectives of the study, the protocols of the trial, and the potential risks associated with the measuring techniques. The endorsement from ADMEC and the right of the subjects to withdraw from the trial were clearly explained. All fourteen subjects indicated their interest and understanding and gave their written consent to participate.

The subjects were divided into four groups. Each of the first two groups comprised four reservists and the last two groups contained three regular soldiers. A multistage fitness test (beep test) to estimate their peak oxygen uptake (VO_{2peak}) was conducted a few days prior to the commencement of the trial. Table 1 shows the physical characteristics of the fourteen participants and the beep test results of the eleven subjects who took part in the beep test.

Table 1: The physical characteristics and estimated VO_{2peak} of the soldiers

Soldier	Age (years)	Mass (kg)	Height (cm)	Beep Test Score (BTS)	Estimated VO_{2peak} from BTS ($mL.min^{-1}.kg^{-1}$)
S1	28	75.2	187	10.3	47.4
S2	37	93.6	174	8.5	41.1
S3	39	91.3	178	n.d.	n.d.
S4	34	97.2	184	10.1	46.8
S5	42	87.3	182	6.1	32.9
S6	42	83.4	178	7.8	39.2
S7	38	84.9	172	n.d.	n.d.
S8	35	67.3	172	9.7	45.2
S9	28	86.7	182	n.d.	n.d.
S10	41	83.7	184	9.0	43.3
S11	25	78.7	178	12.0	53.7
S12	42	66.5	167	13.3	58.2
S13	23	82.8	180	13.2	57.6
S14	23	53.0	172	12.0	53.7
Mean	34.1	80.8	178	10.2	47.2
S.D.	7.3	11.9	5.8	2.3	8.0

S.D. = Standard Deviation
n.d. = not determined

2.2 Schedules and Activities

Schedules and activities of the trial were planned and agreed on advice from the Pilbara Regiment. An inland site, in the vicinity of the intersection of a railway line and the eastbound (towards Roebourne) North West Coastal Highway was chosen as the LUP. Approximately 30 km (30 minutes by road) NE of the Regimental Headquarters (Taylor Barracks) the vehicles turned off the highway, and travelled 15 minutes off-road to reach the LUP. After a route march of 3 km, soldiers then rostered to take up a position at the Observation Post (OP) to conduct surveillance. The OP was at the top of an elevation of approximately 75 m. The route march was 'out-and-back'. It was conducted to simulate the patrol that is normally conducted from the LUP to the OP, these two locations usually being physically separated. The distance of the route march represented a 'worst case' scenario; the OP and LUP are usually no more than one kilometre apart to facilitate the rapid movement required by an operational situation. For the purposes of the study it was more convenient (for data collection) that the OP and LUP be adjacent. Following the observation period a second route march (identical to the first) was conducted to simulate the usual situation whereby soldiers would march back to the LUP. A summary of the planned activities is shown in Table 2.

Table 2: Schedule and activities of the Pilbara trial

Schedule	Activities
1900	Soldiers receive instructions for taking the radio-pills 8 to 10 hours before the trial.
0600	Soldiers report to Regimental Headquarters. One subject is instructed to fast and rest for 45 minutes to allow determination of resting metabolic rate (RMR).
0615	Soldiers are weighed and instrumented with skin thermistors and Polar Sport unit for heart rate monitoring.
0830	Soldiers are transported by surveillance vehicles to the LUP. The oxygen consumption of the subject whose RMR had been determined is measured during the transport and route march. Temperatures are measured by a weather station (Metrosonic 3700) continuously throughout the patrol and observation period each day.
0915	Arrive at the LUP.
0935	Arrive at site for command post.
0950	Trial team set up the anemometer and weather station.
1010	Soldiers commence simulated patrol (~ 3 km patrol in marching order). Oxygen consumption of a designated soldier is measured for 15 minutes (Metamax, Cortex).
1130	Return to OP.
1140	First shift of surveillance. One soldier moves to a position at top of elevation to observe.
1240	Second shift of surveillance.
1340	Third shift of surveillance.
1440	Fourth shift of surveillance.
1540	Surveillance duty completed. Second 3 km route march with VO_2 measured.
1600	Pack up equipment and leave Command Post.
1700	Return to Regimental HQ, soldiers are weighed and debriefed on the events of the day.
1830	Complete data downloading. Reset equipment for next trial day.

On the first day of the trial, the weather became unstable. There were intermittent sunny periods but rainfall became heavy and more frequent towards the latter part of the day. The morning route march was conducted in relatively windy and wet conditions. Torrential rain and gusty conditions were the dominant weather pattern on the second day. These climatic conditions imposed little thermal strain on the soldiers. Heavy rainfall also flooded the highway on the return trip on Day 2 and denied access to the Regimental Headquarters for several hours. The high levels of air moisture caused some equipment failures. Consequently the physiological responses of the soldiers, over the period in which equipment failures occurred, were not measured. The rain also affected the hydration studies as most of the data collected were uninterpretable. For example, soldiers actually gained weight during the route march on Days 1 and 2 as a result of accumulation of rainwater in clothing. Therefore, the attempt to measure sweat production by the method of weight loss was unsuccessful on these days.

Given the possibility that the unseasonal weather would disrupt the rest of the trial, it was decided a new OP, with less likelihood of becoming flooded was selected. It was a remote coastal site, called 'Secret Beach' approximately 22.5 km SW of Karratha and 17.5 km NE of Dampier. The activities were also slightly modified to include a second route march of 3 km in the afternoon to increase the workload of the soldiers. The weather improved on the third and fourth days.

2.3 Experimental Design

The experiments were designed to allow for the pooling of individual data so that physiological responses of up to 16 subjects to thermal stress could be analysed as one data set. That is, each subject would conduct the same activities at the same time of day in similar environmental conditions. It was intended that the activities chosen for the soldiers would be typical of long-range reconnaissance and surveillance missions. The physiological variables measured under these conditions should therefore be indicative of the level of physiological strain the soldiers would have experienced in a routine operation. However, the weather conditions of the first two days of the trial were substantially different to the normal weather pattern of Karratha in February. The cyclonic depression also forced the trial team to change the venue for the last two days of the trial. Due to data loss and equipment failure in the first two days, statistical analysis of the data was restricted to the third and fourth trial day only. Results are therefore presented for the subjects studied on those days (n=6).

2.4 Experimental Procedures

2.4.1 Multistage Fitness Test

A multistage fitness test (beep test) for the estimation of peak oxygen uptake of the volunteers was conducted by the Regimental Medical Officer before the trial commenced. The method used was adapted from the procedures developed by the UK National Coaching Foundation (Brewer et al., 1988). Briefly the subjects ran repeatedly on a flat and non-slippery surface between two markers 20 m apart. The required speed to complete the distance was progressively increased as indicated by an audible signal (beep). Subjects were required to increase their running speed to keep up with the beeps. The test was terminated when subjects could no longer maintain the required tempo. The test level and the number of shuttles the subject completed were recorded. The peak oxygen uptake was estimated by matching the beep test score to a table of predicted VO_{2peak} contained in the user's manual.

2.4.2 Oxygen Consumption (VO_2)

A portable metabolic test system (Metamax®, Cortex, Germany) was used for the measurement of VO_2. Before each experiment, the CO_2 and O_2 sensors were calibrated using a standard mixture of 6.02% CO_2 and 15.94% O_2, with nitrogen comprising the balance, and using ambient air, assuming a composition of 20.93% O_2, 0.04% CO_2 and 79% N_2. The volume transducer was calibrated according to recommended procedures, using a standard 3 L syringe. After each trial the volume transducer and the face mask were deep-disinfected in Deconnex® for at least two hours, followed by rinsing in water.

The VO_2 of only one subject was measured on each trial day. To determine the resting metabolic rate (RMR) which approximates the basal metabolic rate (BMR), the soldier fasted for eight hours before the measurement. On arriving the HQ in the morning, the soldier lay down for about 40 minutes before his VO_2 was measured. Measurements were repeated during the transit to the LUP and the first route march. On each occasion measurements lasted for 15 to 20 minutes. Estimated VO_2 for each soldier was calculated from the soldier chosen for metabolic measurements, adjusted for total weight carried.

2.4.3 Body Temperatures

Gastro-intestinal temperature was measured using a system developed by HTI Inc., USA and PED Inc., USA. The method uses a pill that emits a low power radio signal, the frequency of which is temperature-dependent. The signals were captured continuously by a body core temperature monitor (BCTM, PED, USA). Soldiers were instructed to swallow a pill on the evening prior to participation to ensure that the pill had left the stomach and had entered the intestine. In this way, sudden changes to temperature as a result of eating or drinking were avoided.

Skin temperature was measured with thermistors (YSI 400 Series, USA), fastened by strapping tape (Leukoplast) at three, shaved sites; chest, forearm and medial calf. Area weighted mean skin temperature was later derived using Burton's formula (Burton 1956):

$$\text{Mean Skin Temperature } (T_{msk}) = 0.50\ T_{chest} + 0.16T_{forearm} + 0.34\ T_{calf}\ [^0C].$$

Insulated skin temperature was recorded on the back using a thermistor insulated by a disk of closed cell foam of 10 mm thickness and 32 mm diameter. The thermistor sits in a recess of the disk facing the body surface.

Hard-wired logging was used to collect and store temperature data in the field, prior to down loading to a portable PC at the completion of each trial. The logger used was a Trend Logger (ACR, Canada), which sampled temperatures at two minute intervals.

2.4.4 Heart Rate

Heart rate (HR) was recorded at 1 minute intervals from the R-wave frequency of ventricular depolarisation (Polar SportTester®). The transmitter was fastened around the soldier's torso, and the receiver was put on the wrist. HR data were down loaded to a portable PC at the completion of each trial.

2.4.5 Data Analysis for Body Temperature and Heart Rate

The trial protocol was initially set up so that the four groups of soldiers were to engage in the same activities at the same site on each of the four trial days, assuming similar ambient conditions. Although the total number of soldiers involved was relatively small (14), it would have been feasible to conduct statistical analysis on the physiological variables across the entire activity spectrum had the ambient conditions been similar on each trial day.

Dependent variables were to be analysed using their absolute values across defined periods:
1. Across the first vehicular transport
2. At the LUP
3. Across the first route march
4. Across the observation
5. Across the second route march
6. Across the second vehicular transport

where the scores for a specific activity are averages of the variables (including gastro-intestinal temperature, HR and area weighted mean skin temperature) measured over the period the soldiers engaged in that activity.

Statistical comparison of the absolute value of selected pairs of conditions was performed using Students t-test, with statistical significance set at 5% and corrected for Type I errors for all comparisons, using the Bonferoni method. However, because of the problems with the weather conditions on the first two days of the study, only data collected on Day 3 and 4 were pooled for comparison. Because of the smaller sample size (see Appendix A), the results presented here are therefore more descriptive than analytical. This study should therefore be considered a preliminary examination of the physiological effects on soldiers engaged in long-range patrolling and surveillance operations in hot and dry conditions.

2.4.6 Hydration

Soldiers presented to the preparation area approximately two hours before the activity began. Each soldier had either voided his bladder into a screw-top specimen container after waking or did so on arrival at the preparation area. Samples of urine were also collected during and after the patrol and the volumes other than those collected initially, were measured and recorded. Initial urine samples were retained only for measurement of urinary specific gravity. Soldiers were weighed in briefs, in uniform and in full patrol order (including all instrumentation). Combat ration packs (CRP) and water containers to be taken into the field were weighed. Each soldier was issued with a specimen container, which was used to void the bladder, if needed, during the drive to the LUP. At each phase of the experiment soldier's total body weight was recorded, weight of water containers was noted and the refilled weight of containers was recorded. Urine samples were also measured for volume and SG before being discarded and subjects were provided with a sample container for the next phase.

After the mission, soldiers were weighed in the reverse order, ie full patrol order (including instrumentation), uniform only, and semi-nude. Water containers and CRP were also weighed.

Urine specific gravity was determined for all urine samples to estimate of the hydration status of the soldiers. The instrument used was the Uricon-NE Urine Specific Gravity Refractometer (Atago).

2.4.7 Hydration Calculations

Sweat rate cannot be determined directly in the field. It can most conveniently be estimated by weight loss (disregarding the small losses in weight attributable to respiratory water loss and that of CO_2 production resulting from energy expenditure). Total sweat loss (Sw_{TOTAL}) over the period of each experiment was calculated as:

Initial nude weight - final nude weight + water intake + solid intake - urine output.

An estimate was made of the quantity of sweat lost, but not evaporated ($Sw_{nonevap}$). This was assumed to be sweat that was absorbed by the uniform of the soldier and was calculated as:

(Final clothed weight - final nude weight) - (initial clothed weight - initial nude weight).

Evaporative sweat loss (Sw_{EVAP}) was calculated as: $Sw_{TOTAL} - Sw_{nonevap}$.

Although this method does not correct for all sweat that was lost except those evaporated (ie, 'drippage'), this is not considered a problem in hot and dry environments where nearly all of the sweat is likely to evaporate. Therefore, in genuinely hot and dry conditions, the results obtained using this method should give a good estimate of the true values. However, caution must be exercised in interpreting the results for Days 1 and 2 as the weather conditions were cool, windy and wet.

2.4.8 Environmental Conditions

The ambient temperatures at the trial sites were recorded using a Metrosonic 3700 weather station, USA. The wet bulb (T_{WB}), dry bulb (T_{DB}) and globe (T_G) temperatures were measured, from which the wet bulb globe temperature ($WBGT = 0.1T_{DB} + 0.7T_{WB} + 0.2T_G$) index of environmental thermal stress was calculated. Wind speed was also recorded by a mechanical anemometer.

3. Results and Discussion

3.1 Meteorological Conditions

Table 3 shows the meteorological conditions over the four day period of the trial. The measurements taken for the first two and the last two days of the trial were at different sites. The mean T_{DB} for the first day was the highest among the four days and was 3.8°C higher than the second day, while the difference in mean T_{WB} was only 1.4°C. There were more overcast periods on Day 2 as compared with Day 1. The mean WBGT index for Day 1 was marginally above 30°C while that for Day 2 was only 28°C, suggesting that Day 1 was thermally more stressful. The lower T_{DB} and WBGT and the higher relative humidity recorded on Day 2 were primarily due to the unusually wet weather conditions. The mean wind speed on Day 2 was the lowest and was 0.3 $m.sec^{-1}$.

With the improvement of the weather conditions on Days 3 and 4 and the change of the trial venue to a coastal site, the meteorological conditions of the last two trial days were more stable. The mean T_{DB} for Days 3 and 4 differed by 1.4° C, with the last day slightly hotter. The two mean T_{WB} values were also similar—26.1°C for the third day and 27.1

^{o}C for the fourth. Solar radiation, however was much higher on the fourth day, which registered a mean T_G of 39 ^{o} C. Wind speeds were noticeably higher on Days 3 and 4, with mean values of 1.9 and 2.4 m.sec^{-1} respectively. The WBGT index for Day 3 was 28.5^{o}C. On Day 4 it was 30 ^{o}C.

According to DOHSMAN (1998), the WBGT index can be used as guidance for the planning of physical activities in tropical conditions. The recommendations are:

1. Precautions should be taken to prevent heat illness when the WBGT index approaches 25^{o}C.

2. When WBGT is between 25 and 26^{o}C, appropriate work/rest cycles must be instituted to prevent heat illness.

3. When WBGT index reaches 26 to 28^{o}C, increasing command involvement and supervision of physical activity and water intake are required to prevent heat illness.

4. When WBGT is above 28 ^{o}C, physical activity should be restricted to no more than a total of six hours per day at the recommended work/rest cycle.

The WBGT for all four trial days reached or exceeded 28^{o}C. It is therefore recommended that a work/rest cycle of 30 min work/30 min rest should be adhered to when soldiers conduct heavy work (such as walking at approximately 5 km.h^{-1} with a 30 kg pack) when WBGT is 28^{o}C. At a WBGT of 30 ^{o}C, the corresponding recommended work/rest cycle is 15/45 minutes.

These recommendations apply to acclimatised soldiers. There is anecdotal evidence that some reservist soldiers may only be partially acclimatised to the heat. For these soldiers, exposure to the heat occurs mainly during weekend exercises and during fitness training. However, fitness training is generally conducted in the early morning or late evening. Partial exposure to the heat is unlikely to lead to full acclimatisation (Taylor et al, 1996). Therefore, it is difficult to ascertain the acclimatisation status of the soldiers, in particular the reservists.

It may be concluded that the thermal stress on soldiers on Days 3 and 4 would have been high had they been engaged in vigorous and sustained physical work. However, patrols were conducted for only relatively short periods and over short distances. It is expected that the level of heat strain experienced by these soldiers was not likely to be any greater than 'moderate'. The unseasonally low T_{DB} may also contribute to the lower level of thermal strain. It can be expected that individuals would experience much higher thermal strain if the studies were conducted under normal weather conditions (high T_{DB}) in which environmental heat stress would be much higher.

Table 3: Meteorological conditions at Karratha during the Pilbara trial

Day	T_{WB} (°C)	T_{DB} (°C)	T_G (°C)	WBGT (°C)	Wind Speed ($m.sec^{-1}$)
1	28.1±0.7	33.1±2.0	37.8±4.2	30.6±1.4	1.9±0.5
2	26.7±1.1	29.3±3.4	32.0±6.5	28.0±2.3	0.3±0.4
3	26.1±0.8	30.8±2.1	35.5±4.6	28.5±1.5	1.9±0.9
4	27.1±0.7	32.2±1.5	39.0±2.2	30.0±0.9	2.4±0.4

3.2 Metabolic Turnover

The ability of an individual to perform work at a given intensity and duration will depend on ambient temperature, humidity (ie, WBGT), aerobic and anaerobic capacities. For sustained physical activity, large aerobic power may be required to maintain the work output. Aerobic capacity can be determined by measuring the oxygen consumption during graded exercise in which the work output eventually exceeds the aerobic capacity of the individual. The peak VO_2 (VO_{2peak}) is the maximum rate at which oxygen could be consumed during the test and is a good indicator of the maximal aerobic power. In contrast, minimal rate of oxygen consumption required to sustain the body's vital functions is denoted as basal metabolic rate (BMR). Under appropriate conditions, ie fasting, no recent physical activity and rested, BMR can be approximated by determining resting metabolic rate (RMR). BMR typically constitutes 60 to 75% of the daily energy expenditure of an average person engaging in moderate physical activities.

The determination of the VO_{2peak} is best performed in a laboratory. It is not always practical to have the measurements done in uncontrolled field conditions. Specific tests have been developed to predict the VO_{2peak}. A multistage beep test was employed to predict the VO_{2peak} of the subjects participating in the study (Fig 1). The estimated VO_{2peak} ranged from 32.9 to 58.2 $mL.min^{-1}.kg^{-1}$ with an average of 47.2 $mL.min^{-1}.kg^{-1}$. This mean value is slightly above the averages (40 to 45 $mL.min^{-1}.kg^{-1}$) typically recorded for sedentary male subjects (McArdle et al., 1991) and is higher than the mean value (41.6 $mL.min^{-1}.kg^{-1}$) found for 108 randomly selected, healthy Australian men aged 30 to 39 (DASETT, 1992).

Table 4: Mean rate of oxygen consumption (mL.min^{-1}.kg^{-1}) of one soldier from each day measured at rest (RMR), during vehicular transport ('transit to LUP') and on patrol ('during route march')

Day	Subject	RMR*	VO_2 during transit to LUP	VO_2 during route march	Estimated VO_{2peak}
1	S1	4.0 (8.4%)**	3.9 (8.1%)	25.1*** (53.0%)	47.4
2	S8	5.4 (12.0%)	5.2 (11.4%)	28.5 (63.0%)	45.2
3	S10	3.9 (9.0%)	2.5 (5.8%)	20.1 (46.5%)	43.3
4	S13	3.5 (6.1%)	4.1 (7.2%)	24.2 (42.1%)	57.6

* RMR measured at Pilbara Regiment HQ before transit to LUP. VO_{2peak} estimated from the 'Beep' test (see text).
** Figures in parentheses represent percentage of VO_{2peak} of the VO_2 measured at the specific phase of the experiment
*** Measurement of VO_2 for subject S1 at route march lasted for 2 minutes only due to the detachment of the gas line to the portable ergospirometer.

Table 4 shows the mean oxygen consumption (VO_2) of four subjects, measured at different phases of their corresponding study day. The range of RMR values (0.25 to 0.34 L.min^{-1}) measured at HQ falls within or just outside the range (0.16 to 0.29 L.min^{-1}) of the BMR of the general American population (McArdle et al., 1991). The metabolic turnover measured was therefore considered a reasonable approximation of the soldiers' BMR.

When in transit to the LUP, VO_2 was consistently similar to RMR. In fact, the specific VO_2 (2.49 mL.min^{-1}.kg^{-1}) for subject S10 was lower than his RMR (3.89 mL.min^{-1}.kg^{-1}, this subject slept during transit). Open top vehicles were used for transport the soldiers and as a result, subjects were fully exposed to radiant heat. The similarity of the specific VO_2 recorded during transport and the RMR suggests that radiant heat alone has relatively little impact on the metabolic turnover in the short term; (duration of transport was only ~ 30 minutes). The cooling effect of air movement during transit may also alleviate heat strain due to solar load. In general the energy expenditure of the soldiers during transport constituted approximately 10% (range: 5.8 to 11.4%) of their estimated VO_{2peak}. This suggests a very low work load and it is inferred that the soldiers were not thermally stressed in the transit phase.

The route march resulted in a steep rise in VO_2 compared with the measurements during the other two phases. The highest was recorded on subject 8 (Day 2) with a mean value of 28.5 mL.min^{-1}.kg^{-1} whereas the lowest was 20.1 ml.min^{-1}.kg^{-1} (subject S10, Day 3). These specific VO_2 values, measured on different subjects, different

terrains and different days all fall within a narrow range. This suggests that the soldiers paced themselves in the route march so that there was little difference in their workload (Table 5). The small difference in the percentage of their specific VO_2 to the estimated VO_{2peak} also supports this contention. In general, the soldiers worked at approximately 50% of their VO_{2peak} from which it is inferred that the work load is likely to be sustainable for many hours, provided that environmental heat stress does not lead to higher heat strain.

Table 5: Estimated oxygen consumption (corrected for total weight carried) of the soldiers during route march

Subject	**VO_2 ($L.min^{-1}$)**	**Specific VO_2 ($mL.min^{-1}.kg^{-1}$)**	**Work Intensity (% of VO_{2peak})**
S1	1.54	20.5	43.2
S2	2.17	23.2	56.4
S3	1.99	22.8	NE
S4	2.16	22.2	47.4
S5	1.87	21.4	65.0
S6	1.69	20.2	51.6
S7	1.92	22.6	NE
S8	1.65	24.5	54.1
S9	1.92	22.1	NE
S10	1.72	20.1	46.5
S11	1.72	21.9	40.8
S12	1.43	21.6	37.0
S13	1.91	23.1	40.1
S14	1.49	28.0	52.2

NE = Not estimated as the subjects did not take part in the beep test

3.3 Physiological Variables

3.3.1 Core Temperature

Core temperature, or deep body temperature, is a key indicator of the thermal status of an individual. When there is no heat gain or loss to the body, the core temperature is maintained at approximately 37°C. However, when there is a net gain of heat energy due to exercise and/or a high heat load from the environment, the core temperature will start to rise. The human body has various adaptive mechanisms to maintain a stable, albeit higher body temperature when work has to be conducted. However, in extreme conditions, under which these mechanisms fail to dissipate the metabolic heat sufficiently fast to the environment, the accumulated heat energy can raise the core temperature to dangerous levels which, if unchecked, could result in fatality. It is therefore imperative to examine the relationship between the deep body temperature and the levels of work intensity for military personnel deployed to the tropics so that strategies to minimise thermal casualties can be developed.

Figure 1 shows the mean core temperatures of individuals at different phases of the experiment for the four study days. For Day 1 and Day 2, core temperature profiles during the route march in the afternoon (V2) were not relevant as a result of the cool/rainy conditions. Moreover, core temperature data of soldiers recorded on the return trip to the Regimental Headquarters on Day 2 were lost because of the heavy rain.

The mean core temperature of the four soldiers at the commencement of the experiment for Day 1 to Day 4 was 37.6, 37.3, 37.6 and 37.2 °C respectively. They were virtually unchanged (37.7, 37.3, 37.3 and 37.2 °C) during transit to the LUP. While the soldiers were being transported, their work intensity was similar to that of their resting state (Table 1). Increase in thermal strain, if any, would therefore be primarily due to the additional stress from ambient temperature and solar heat. The observation of little difference in the mean core temperature at these two phases of the study on all four days suggests that solar heat loads experienced by the subjects during transit had relatively little impact on thermal strain experienced by the soldiers.

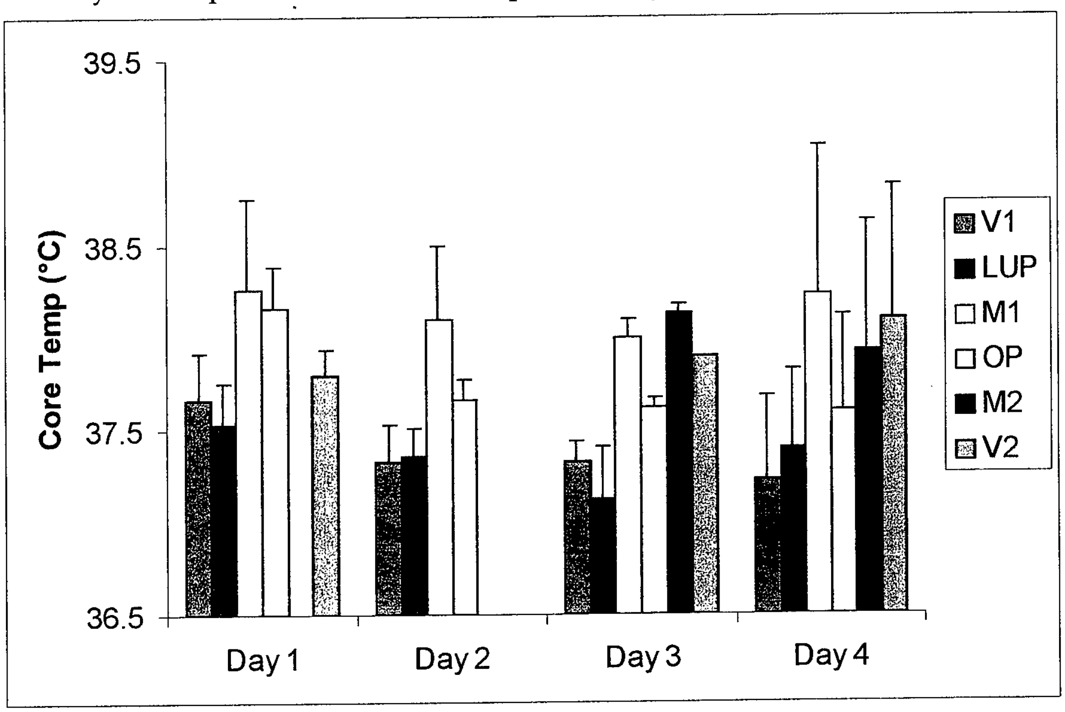

Figure 1. Mean core temperature (°C) of soldiers at different phases of the study for the four study days. V1 = Vehicular transport to the line up point; LUP = Line up point; M1 = First route march (am); OP = Observation post; M2 = Second route march (pm); V2 = Vehicular transport to regimental headquarters. There were no M2 for Day 1 and Day 2 and the data for V2 on Day 2 were completely lost due to heavy rain. The values for the M1 and M2 phases were mean peak core temperature.

During the study, the differences in the weather conditions and the change of the study venue are confounding factors that make data pooling from all four study days invalid. Only data from Day 3 and Day 4 were combined because these were the only days on which consistently hot/dry conditions were experienced. Given that only a very small

sample of subjects was available on each day, the statistical power for comparisons was generally low. Indeed, Student's t test revealed no statistically significant difference (at $p>0.05$ level) in the mean core temperature between activities for subjects of Days 3 and 4. There is noticeable similarity however, in the trend for changes of core temperature across activities on each day. As would be expected, the core temperature reflected both time-of-day and work intensity, being lowest when the OP was set up, during vehicular transport and when sedentary at the LUP, and highest during the patrol. The morning route march conducted each day and on the afternoon of Days 3 and 4, which involved soldiers carrying a relatively heavy load (25 to 45 kg) and walking a distance of 3 km, was an activity of high work intensity according to DOHSMAN (1998). The highest peak core temperature of 39.1°C of a subject was also recorded during the afternoon route march on Day 4 for a very short period of time (approximately 2 minutes), suggesting a moderate level of thermal strain. In general, the core temperatures of all fourteen subjects recorded during the studies were below 38.5°C on 90% of occasions, with the remaining 10% under 39°C. These results would support the contention that the degree of thermal strain was at worst, moderate. It is of relevance that the mean core temperatures recorded during the return trip (V2) to HQ were comparable to those recorded during route marches, and were substantially higher than the temperature recorded during the transport in the morning (V1). This is despite the work rate being approximately the same on each occasion. The timing of the return trip took place almost immediately after the route march. It is known that changes in core temperature lag behind the changes in exercise intensity (Givoni and Goldman, 1972; Berlin et al; 1975). The higher values observed at V2 could be an expression of this overshooting effect. It is noted that the timing of the V2 phase matched the zenith of the diurnal pattern of the deep body temperature. This will also contribute to a higher reading of the core temperature.

3.3.2 The Area Weighted Mean Skin Temperature

The area weighted mean skin temperature can be used in conjunction with the core temperature to indicate the heat content of the body. Changes in skin temperature are primarily controlled by blood flow to the skin and local sweating rate. When core temperature remains constant, the sweating rate is directly proportional to the area weighted mean skin temperature (Nadel et al; 1971). It therefore plays an important role in regulating the evaporative cooling of the body.

Figure 2 shows the average area weighted mean skin temperature of the soldiers at different phases of the four experiments. Results collected on the first and second days may be invalid as a result of the unexpected rain. It is possible that the rain caused cooling of the sensor, resulting in much lower recorded skin temperature. Consequently, the mean values calculated on these two days were probably not indicative of the true skin temperature. The initial average area weighted mean skin temperature for Day 1 to Day 4 was respectively 34.3, 33.5, 33.1 and 35.2°C. They were comparable to the corresponding temperatures at V1 (33.7, 33.7, 33.6 and 35.1 °C), a phase which involves low energy expenditure. At the phase M1 on Day 1 to Day 4 and phase M2 on Day 3 and

Day 4, activities requiring much higher work outputs, the average area weighted mean skin temperature was 2 to 3°C higher than the corresponding values at the commencement of the experiment. However, measurements at the OP and V2 phases were only marginally higher than the starting values. Again this may indicate the effects of the diurnal changes of the body temperature.

It is obvious that a higher work load will result in higher body heat production, leading to greater blood flow to the skin and higher skin temperature. It was duly observed in this study that changes in the area weighted mean skin temperature followed closely the changes in the core temperature (Pearson correlation coefficient = 0.37, n= 62 (from 14 subjects), $p>0.01$), attributable to thermoregulatory feed back mechanisms of blood flow to the skin. Comparison of the changes of the pooled (Day 3 and Day 4) average area weighted mean skin temperature across activities does not show any significant difference (at $p>0.05$ level), presumably due to the small sample size available for the analysis. Nevertheless, the trend observed shows clearly that skin temperature rises with respect to increased physical activity and approaches the corresponding core temperature towards the end of the experiment.

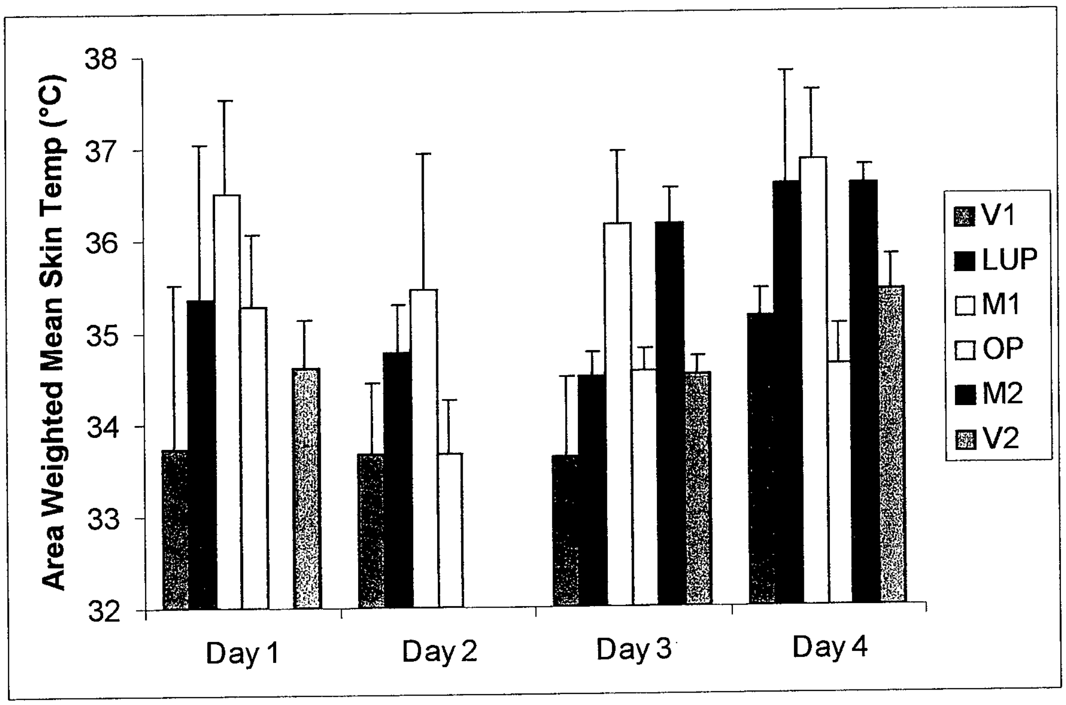

Figure 2. Average area weighted mean skin temperature (°C) of soldiers at different phases of the study for the four study days. V1 = Vehicular transport to the line up point; LUP = Line up point; M1 = First route march (am); OP = Observation post; M2 = Second route march (pm); V2 = Vehicular transport to regimental headquarters. There were no M2 for Day 1 and Day 2 and the data for V2 on Day 2 were lost due to heavy rain. The values for the M1 and M2 phases were average area weighted mean peak skin temperature.

3.3.3 Heart Rate

Heart rate can be used to indicate the cardiovascular strain and the relative strenuousness of physical activities in healthy subjects. However, its usefulness as a heat strain index is limited as HR is an extremely sensitive physiological variable. It is regulated by a number of extrinsic and intrinsic factors. Nevertheless, all other factors being equal, HR can be used as an indicator of the integrated cardiovascular strain due to physical exertion and external heat stress.

Figure 3 shows the mean HR of the subjects at different phases for the four study days. Again, loss of data on Day 1 and Day 2 was substantial as equipment malfunctions were common. This was particularly serious on Day 2 when the study team was held up by the rainstorm on its return trip to the Regimental HQ. Consequently, only the data from Day 3 and Day 4 were pooled for comparison.

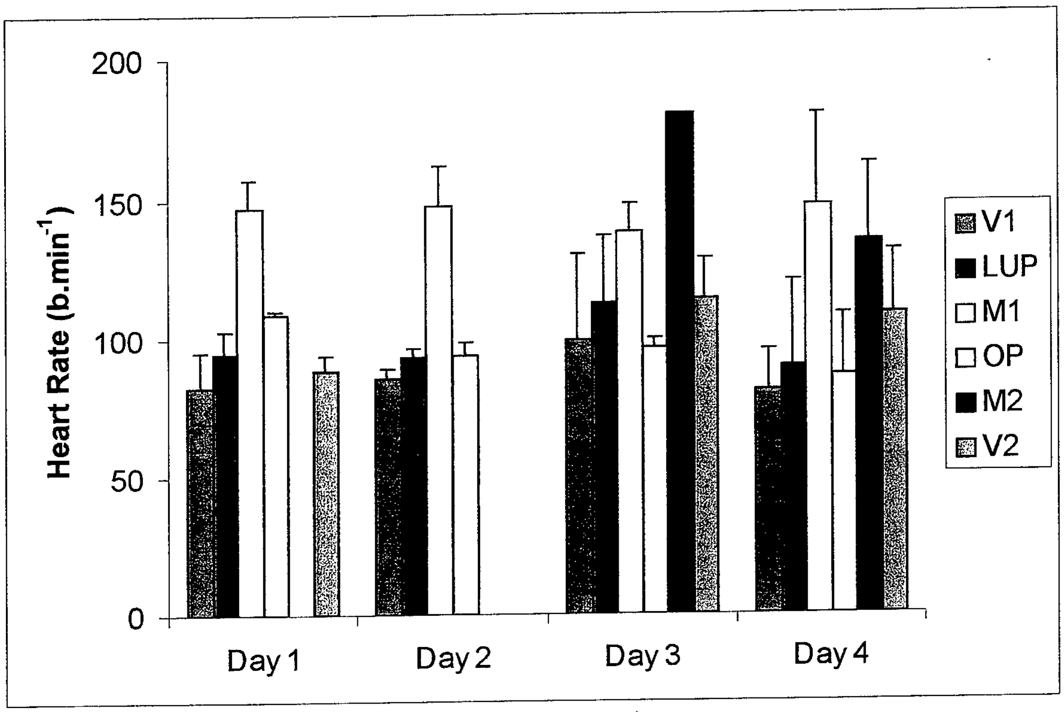

Figure 3. Average heart rate (b.min^{-1}) of soldiers at different phases of the experiment for the four study days. V1 = Vehicular transport to the line up point; LUP = Line up point; M1 = First route march (am); OP = Observation post; M2 = Second route march (pm); V2 = Vehicular transport to regimental headquarters. There were no M2 for Day 1 and Day 2 and the data for V2 on Day 2 were lost due to heavy rain. The values for M1 and M2 phases were average peak heart rates.

The average HR at the commencement of activities for Day 1 to Day 4 was 81, 77, 89 and 78 b.min^{-1} respectively. The data collected on Day 2 were calculated from only two

subjects and over a very short period of time. These values reflected the low level of physical activity of the subjects and were indicative of their resting HR. During road transport to the LUP, mean HR remained at approximately 100 b.min^{-1} (range: 81 to 112 b.min^{-1}) on all four study days, again indicating the relatively low level of physical strain. However, the rate escalated to approximately 143 b.min^{-1} (range: 138 to 148 b.min^{-1}) during the morning route march. This is attributable partly, but perhaps not entirely, to the relatively strenuous work output. One indication of thermal stress is an increase in HR that is disproportionate to that expected from the work rate alone. From section 3.3, the work rate associated with patrolling was approximately 50% of VO_{2peak}. There is a linear relationship between HR and work rate (Astrand and Rodahl, 1986). Therefore, working at about 50% of VO_{2peak} would be expected to be accompanied by a HR of about 50% of the 'HR reserve'. That is, if minimum HR is about 60 b.min^{-1} and maximum HR is about 186 b.min^{-1} (the approximate means for healthy and physically fit men of average age of 34, Astrand and Rodahl, 1986), the HR associated with working at 50% of VO_{2peak} would be expected to be approximately 123 b.min^{-1} {calculated as [(186 -60)/2] + 60} . The observed mean HR of 143 b.min^{-1}, at approximately 50% of VO_{2peak}, is evidence that the soldiers were experiencing thermal strain to a moderate degree.

HR then dropped to approximately 100 b.min^{-1} while at the OP. The mean values at V2 were slightly higher than the corresponding values at V1, an effect possibly associated with the diurnal cycle of body temperature, higher ambient temperature in the afternoon and prior physical activities. The highest mean HR of 180 b.min^{-1} was recorded on Day 3 during the afternoon route march. This is likely to be close to the maximum HR of the soldier and indicates a high level of heat strain. The pooled data of Days 3 and 4 show no difference (at $p>0.05$ level) in mean HR across different activities, presumably due to the small sample size. Despite this, it is obvious that changes in HR are closely associated with changes of physical exertion during the study, and the HR data indicate moderate heat strain during the morning patrol and high heat strain during the afternoon patrol.

3.3.4 Hydration

Appendix B shows the raw data for hydration status of the six soldiers who were exposed to reasonably hot/dry conditions (Days 3 and 4). Table 6 summarises the hydration results and Table 7 shows the variation of urine specific gravity over time during the two days of hot/dry conditions.

From both Table 6 and Table 7, subject S4 can be considered to be an 'outlier'. This subject drank prodigious quantities of water, was the only subject to undergo an increase in body weight during the experiment and the only subject whose urinary specific gravity decreased from beginning to end of the experiment. The significance is that his results are not typical of the group, so two means are presented for the hydration data - an overall mean and the mean for subjects S1, S2, S3, S5 and S6. In the discussion below, these subjects are referred to as the 'five indicative subjects'.

Table 6: Summary of hydration parameters for subjects studied on Days 3 and 4

SUBJECT NUMBER	TOTAL WT LOSS (kg)	TOTAL WATER INTAKE (L)	FOOD INTAKE (kg)	TOTAL URINE PROD. (L)	TOTAL SWEAT (L)	TOTAL SWEAT RATE ($L.h^{-1}$)	NON-EVAP SWEAT (L)	NON-EVAP SWEAT RATE ($L.h^{-1}$)	EVAP SWEAT (L)	EVAP SWEAT RATE ($L.h^{-1}$)
S1	1.85	3.30	0.50	0.07	5.58	0.76	0.40	0.05	5.18	0.71
S2	0.75	1.95	0.60	0.23	4.22	0.58	0.45	0.06	3.77	0.52
S3	2.20	1.75	0.70	0.46	4.19	0.57	0.55	0.08	3.64	0.50
S4	-0.45	9.10	0.20	2.03	6.82	0.84	0.20	0.02	6.62	0.82
S5	0.75	2.95	0.80	1.05	3.45	0.43	0.05	0.01	3.40	0.42
S6	0.50	3.20	0.55	0.31	3.94	0.49	0.55	0.07	3.39	0.42
MEAN*	**0.93**	**3.71**	**0.56**	**0.69**	**4.70**	**0.61**	**0.37**	**0.05**	**4.33**	**0.56**
SD*	**0.96**	**2.72**	**0.21**	**0.74**	**1.26**	**0.16**	**0.20**	**0.03**	**1.30**	**0.16**
MEAN❋	**1.21**	**2.63**	**0.63**	**0.42**	**4.28**	**0.57**	**0.40**	**0.05**	**3.88**	**0.51**
SD❋	**0.76**	**0.73**	**0.12**	**0.38**	**0.79**	**0.13**	**0.21**	**0.03**	**0.75**	**0.12**

*Mean and SD for all subjects

❋ Mean and SD for subjects S1, S2, S3, S5 and S6

Table 7: Time course of urine specific gravities (SG) for the six subjects who were exposed to hot/dry conditions (Day 3: Subjects S1-S3 and day 4: Subjects S4-S6) and mean SG for initial and final conditions for all subjects and for subjects S1, S2, S3, S5 and S6 (see text).

Time✣	S1	S2	S3	S4	S5	S6	MEAN✣	MEAN❋
Initial*	1.030	1.017	1.019	1.012	1.012	1.011	1.017	1.018
0810				1.006				
0940		1.010	1.010	1.004	1.003	1.003		
1210		1.027						
1400				1.007				
1450	1.028		1.020					
1530				1.004	1.018			
Final**	1.036	1.032	1.027	1.004	1.020	1.021	1.023	1.027

*Initial urine sample was provided on arrival at Taylor Barracks, or as soon thereafter as possible (between 0630 and 0730).

**Final urine sample was provided on return to Taylor Barracks (1530 for subjects S1-S3 and 1630 for subjects S4-S6).

✣ Means for all subjects.

❋Means for S1, S2, S3, S5 and S6 (see text).

The participating subjects were not engaged in arduous, long-range foot patrols in the heat. For the most part they were sedentary in the shade or travelling in vehicles (with sun exposure, but also with exposure to rapidly moving air and hence evaporative cooling). Compared to results obtained previously for soldiers engaged in short-term, arduous patrolling in hot and dry and hot and wet conditions (Amos et al, 1998) mean sweat rate on this study was not high. Amos et al (1998) found that soldiers engaged in patrolling at High Range Training Area (hot and dry) and Land Command Battle

School (hot/wet) at the same time of year as the present study (February) had mean sweat rates of 1.0-1.5 $L.h^{-1}$.

However, the results presented here do not reveal excessive sweat rate during the patrolling phase. This phase was not of sufficient duration (< one hour) to obtain reliable results, a rate exceeding 1.5 $L.h^{-1}$ during patrolling may be inferred since:

1. Sweat rate was probably quite low during periods other than the patrolling phase (activity level was low and exposure to solar radiation was minimal), indicating that when the soldiers did sweat, they must have done so profusely to average 0.61 $L.h^{-1}$;
2. The rates of 1.0-1.5 $L.h^{-1}$ reported by Amos et al (1998) for soldiers in hot/dry and hot/wet environments involved patrolling in full shade (hot/wet) or partial shade (hot/dry). In the present study, on Days 3 and 4, patrolling occurred in full sun. The resultant solar load may well have led to sweat rates of more than 1.5 $L.h^{-1}$ during the patrolling phase.

On average, 92% of sweat was evaporated (4.33 L of 4.70 L). This is to be expected in a dry environment because the air has a low vapour pressure. This has implications for sweating efficiency; with high evaporation, sweating leads to cooling. Soldiers in this study are therefore expected to have a lower risk of heat illness than would have been the case in a hot/wet climate.

From the relatively low work rate experienced by the subjects, the risk of heat illness should be minimal under the conditions experienced during this study. The implications for soldiers on long-range foot patrols in hot and dry environments are unknown; only further experimentation will resolve this.

The five indicative subjects lost weight over the period of the activity, despite consumption of 560 g of food on average. The loss can be attributed to dehydration. The increase in mean urinary specific gravity (from 1.018 to 1.027) of the five indicative subjects indicates that moderate hypohydration occurred in those subjects. Normal urinary SG is considered to be in the range 1.010 - 1.025. Hence mean initial urinary SG was at the mid-point of the normal range for the five indicative subjects, and mean final SG was slightly above normal, a condition attributable to a moderate level of hypohydration. In the five indicative subjects, mean total sweat volume exceeded water consumption by 0.8 L, verifying that a net loss of water occurred during the experiments.

Two subjects appear to have become quite hypohydrated: S1 (2.1% of body weight) and S3 (2.8%). The high final urinary SGs of these subjects (1.036 and 1.027) and low urine output for S1 (0.07 L) support the conclusion that they were at least 'moderately' hypohydrated. According to Burr (1991) a level of hypohydration of 2-3% of body weight "reduces physical capacity and heat tolerance". The findings that 33% of the subjects were hypohydrated suggests that dehydration could cause performance

decrement even though the work rate of the soldiers was not excessive. The importance to military performance of avoiding such 'voluntary dehydration' should be emphasised to commanders and to individual soldiers. A Commanders' guide to reduce the risk of dehydration-induced heat illness for Land forces is now available (Cotter, 1999). At the other end of the hydration scale, one subject (S4) had a final urinary SG (1.004) that was indicative of excessive water consumption. This subject drank more than 9 L of water during the 8 hours of activities (contrasting with mean water intake of 2.1 L for the other five subjects). His urine output was approximately equal to the total urine output for the five indicative subjects. On a previous study we have noted the existence of a tendency by a small minority of soldiers to drink a huge amount of water (Amos et al, 1998). On a recent study conducted with Air Defence Ground Staff at RAAF Base Scherger, one subject was observed who suffered the symptoms of mild water intoxication (dizziness, disorientation, electrolyte imbalance) after drinking 14 L of water overnight. This subject had previously suffered from the effects of hypohydration and wanted to avoid a repetition. Although hypohydration is a far greater problem in the field than water intoxication, commanders should note that it is possible to consume too much water and that this can also be debilitating.

In summary, with valid results available for only six subjects, and with soldiers engaged in mostly sedentary activity for a large proportion of the period observed, no definitive conclusions are possible on the effects of heat on soldiers who are conducting long-range reconnaissance and surveillance in hot and dry environments. The most significant finding is the tendency to moderate levels of hypohydration, despite relatively low exposure to environmental heat stress and a relatively low work rate. This trend suggests that exposure to greater heat stress, for example, when soldiers are patrolling for many hours per day in hot and dry environments has significant potential to adversely affect cognitive and physical performance.

3.4 Gastrointestinal Pill Reliability

The measurement of body core temperature in subjects generally involves the use of standard obtrusive methods using devices such as rectal and oesophageal thermistors. These procedures induce not only a psychological objection but can be quite uncomfortable for a subject when *in situ*. Hence, the use of a gastrointestinal (GI) temperature transmitter appeals not only to scientific investigators, but most importantly, is more likely to be acceptable to the subjects. The use of a disposable GI pill, transmitting a frequency influenced by the temperature of its environment, and an accompanying receiver/logger, enables the measurement of body core temperature to be performed in the laboratory or during field exercises or studies. This technology allows a more flexible approach for the monitoring of thermal strain amongst subjects who are regularly exposed to extreme thermal stress. Furthermore, the GI pill can be used to quantify and verify the effect of adverse working environments (internal and external) on people at potential risk of thermal injury and to determine safe working exercise intensities during dynamic activities amongst specific populations.

The current evidence suggests that body core temperature recorded by the GI pill appears (on average) between temperatures recorded by rectal and oesophageal thermistors. This observation is well documented and follows the expected physiological theory associated with thermal changes and haemodynamics during static and dynamic activities (O'Brien *et al.*, 1997; Amos *et al.*, 1998; Cotter *et al.*, 1998). The GI pill tracks rectal temperature more closely than oesophageal due to its location and the thermal attributes of its surroundings in the lower GI tract. Subsequently, GI pill recorded temperatures are slightly more responsive than rectal and, unlike oesophageal monitors, are not contaminated by acute transient changes in temperature (such as that due to drinking cold fluids). Therefore it appears that the GI pill system is a reliable and valid measure of whole body thermal strain, comparable to rectal and oesophageal recordings without the associated obstacles.

Nevertheless, there are also issues associated with using the GI pill system. The major problem is determining the most appropriate time to ingest the pill. The ingestion of the pill and its progression through the GI tract may provide a major source of variability during the pill's journey, particularly if the recordings are made within 1-2 hours after ingestion. The GI pill is required to descend into the duodenal portion of the small intestine so as to remove any contaminating effects of fluid ingestion. Nevertheless, slight variations in temperature are also observed throughout the small and large intestines, mainly associated with variations in bacterial activity and locations of internal anatomical structures along the GI tract. However, laboratory and field trials (Amos *et al.*, 1998; Cotter *et al.*, 1998) have confirmed that if the pill is taken just prior to going to bed the night before use, or more than 2 hours prior to logging data, the influence of gastric filling is minimised or removed completely.

The other difficulty encountered when using this telemetry system is the administration of a large solid pill/capsule. The current technology is able to provide an ingestable GI pill of dimensions approximately 2 cm in length by 1 cm in diameter. Although the geometry of the pill is inconsequential compared to a food bolus during meal ingestion, the process and psychological effects of such a procedure may become hazardous in some subjects. It is advisable to ask if the subject has problems swallowing any solid form of medication. In all cases, close supervision of subjects is recommended (if feasible) when ingestion of the pill takes place. If the pill is taken away to be swallowed before retiring for the night before the experiment begins, the subject is encouraged to swallow the pill in the presence of another person.

The overall reliability of the GI pill system has been found to be very high. In the heat strain study conducted in the Pilbara region, data was collected successfully from 86% (12/14) of the subjects during six (V1, LUP, OP, M1, and M2) of the eight exercises conducted each day. The two GI pill systems that failed did so before the soldiers commenced the trial. The faulty receiving/logging units were inoperative and not used throughout the remainder of the exercise. It was observed that when a GI pill system (pill and logger) had been functional at the start of each day, 100% of the data was successfully recorded. Hence the problems associated with the units were a function of

their robustness during transport and not associated with failure during the daily activities. The GI loggers during the remaining two activities performed on each day (V2 and M2) were found to have collected only 57% (8/14 subjects) and 43% (6/14 subjects) of the total possible GI temperature data, respectively. However in this case, GI pill system failures were not due to equipment or electronic deterioration but caused by adverse environmental conditions experienced on the first two days of the study. Therefore data collection during these periods was aborted.

Other problems that were encountered, and may have influenced the reliability of the GI pill system were the proximity of the receiver/logger units to the subjects and external electrical interference. The position of the receiver/logger units in relation to the subject was critical, as the range between GI pill transmitter and receiver/logger is only 60 cm. Hence, location of the GI logger around the waist (in a pouch attached to the webbing) was ideal during this exercise (webbing remained in place for the entire length of this exercise). Electrical interference, either cross talk from other GI pills or external RF signals, did not appear to adversely affect the recorded data. Since the GI pill range is very low, interference from other pills is not expected. However, RF signals may contaminate the received data, but since no radio transmissions were made during these exercises results were not affected. Nevertheless, in situations where there may be high RF transmissions, the integrity of the recorded GI pill data cannot be guaranteed. Further studies are required to investigate whether specific RF bands influence the received GI pill data.

4. Conclusions

This study was designed to examine the physiological performance of soldiers on long range reconnaissance and surveillance duty. Unfortunately the validity of the outcomes of the trial was restricted by the small sample size and the unseasonal weather conditions. Nevertheless, some useful information was obtained and the following conclusions are drawn:

4.1 Stress-related Factors

1. The meteorological conditions at the time of the studies were, in general, not thermally stressful, with the exceptions of the conditions at mid-day on Days 3 and 4 when soldiers conducted their second patrol.
2. Solar radiation did not result in a high thermal strain in the soldiers during the transport phase, presumably as it was counteracted by convective heat losses due to higher air movement. However, the solar load might have contributed more significantly to higher thermal strain during the morning and afternoon route march.
3. The VO_2 measurements suggested that the work load for the soldiers during the transit phase was extremely low, close to their RMR, but approached 50% of their VO_{2peak} during the route march. This moderate work rate was likely to be

sustainable for a considerable period of time, as long as the environmental heat stress remained moderate.

4.2 Strain-related Factors

1. A moderate degree of heat strain was indicated in soldiers by their core temperature, area weighted mean skin temperature and heart rate.
2. Evaporative cooling is effective for heat dissipation under the trial conditions as 92% of the sweat lost was evaporated.
3. Trends in hydration status on the very limited number of subjects from whom valid results were obtained suggested that hydration is likely to be a real problem when soldiers are required to work hard in hot/dry conditions. Paradoxically, this study also showed that excessive water consumption may occur in some subjects.

4.3 Measurement Techniques

1. The reliability and performance of the GI pill technology for measurements of core temperature in field conditions were acceptable. Electrical interference, from cross talk between GI pills did not seem to affect the recorded data. It was noticed that some radio pills had not generated recordable signals at the start of the trial, presumably either due to a loss of the pill or malfunctioning of the pill itself.
2. The Polar Sport Tester Unit, despite claims by the manufacturer that it is 'water proof', was found to be susceptible to moisture penetration, leading to loss of some HR data.
3. The method of estimation of sweating rate by weight loss is invalid if subjects are exposed to rain during the study.
4. The anemometer must be shielded from direct exposure to sunlight or the display unit will not function properly.

5. Recommendations

The current study showed only moderate levels of thermal strain in soldiers conducting long range reconnaissance and surveillance activities. This is probably not a true reflection of the typical strain the soldiers would experience if the weather conditions were more stressful. However, this study provides information that may be useful to the Pilbara Regiment to improve their heat stress management strategy. Soldiers undergoing long range patrolling would clearly experience much higher levels of heat strain under more typical weather conditions of the region. Long range patrolling, however, is not a typical operation undertaken by the Regiment. And for routine operations, it is unlikely that heat strain will pose a problem. Nevertheless, the outcomes of the Soldier Combat Systems Enhancement Studies (Amos et al, 1998) and the DOHSMAN (1998) have provided important guidance for the development of

management strategies to minimise heat casualties for military operations in the tropics. Based on the recommendations of these documents, it is recommended that

1. The activities of the soldiers during operations should be closely monitored. According to DOHSMAN, an hourly cycle of 30 min work/30 min rest for subjects engaged in heavy exercise (such as route march in full patrol order) is recommended when WBGT reaches 28°C. Additional resting time should be planned if WBGT exceeds 30°C.
2. It is critical to maintain adequate water intake to minimise the deleterious effects caused by thermal strain. It was also noted that in some circumstances, inappropriately high levels of water consumption do occur. Optimisation of water consumption is essential to maintain appropriate hydration status of the soldiers. A minimum fluid intake of $1.5 L.h^{-1}$ is recommended when subjects engage in arduous activities such as route marching or patrolling in hot/dry environments.
3. The study should be repeated to determine the true level of thermal strain and the effects on hydration status with an Army unit conducting long-range patrolling in a hot/dry environment. A minimum of 15 subjects is suggested as appropriate to provide adequate statistical data and the activities during operations should be standardised across subjects and over the period of the study.

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Appendix A:

A.1 Matrix of Student's t-test for the Combined Physiological Variables on Days 3 and 4 Across Different Activities

1. *Core Temperature – Figures are t-test scores for comparison of the mean core temperature of two different activities (n=6)*.*

	VT1	LUP	M1	OP	M2	VT2
VT1	-	0.867	0.000	0.002	0.001	0.001
LUP	0.867	-	0.001	0.028	0.006	0.001
M1	0.001	0.0	-	0.005	0.655	0.393
OP	0.002	0.028	0.005	-	0.014	0.010
M2	0.001	0.006	0.655	0.014	-	1.000
VT2	0.001	0.001	0.393	0.010	1.000	-

*No significant difference (p>0.05) was observed in core temperature across different activities.

2. *Heart Rate – Figures are t-test scores for comparison of the mean heart rate of two different activities (n=6)**

	VT1	LUP	M1	OP	M2	VT2
VT1	-	0.199	0.015	0.083	0.018	0.039
LUP	0.199	-	0.015	0.300	0.013	0.155
M1	0.015	0.015	-	0.001	0.933	0.065
OP	0.838	0.300	0.001	-	0.007	0.045
M2	0.018	0.013	0.933	0.007	-	0.104
VT2	0.039	0.155	0.065	0.045	0.104	-

*No significant difference (p>0.05) was observed in heart rate across different activities.

3. *Average Area Weighted Mean Skin Temperature – Figures are t-test scores for comparison of the average area weighted mean skin temperature of two different activities (n=6)**

	VT1	LUP	M1	OP	M2	VT2
VT1	-	0.023	0.000	0.623	0.018	0.070
LUP	0.023	-	0.076	0.117	0.159	0.159
M1	0.000	0.076	-	0.000	0.579	0.001
OP	0.623	0.117	0.000	-	0.000	0.105
M2	0.018	0.159	0.579	0.000	-	0.000
VT2	0.070	0.159	0.001	0.105	0.000	-

*No significant difference (p>0.05) was observed in overall mean skin temperature across different activities.

A.2 Raw Data for Hydration Status

Pilbara study, pooled data for Days 3 and 4

Phase 1: Pre-Patrol (In-Barracks)

NO	NUDE WEIGHT (KG)	CLOTHED WEIGHT (KG)	PATROL ORDER (KG)	INITIAL WEIGHT OF WATER (KG)	WEIGHT OF CRP (KG)
S1	86.70	90.25	125.85	7.70	1.55
S2	83.65	86.90	113.05	3.75	1.55
S3	78.70	82.25	113.30	4.45	1.55
S4	66.50	69.45	94.15	6.70	1.75
S5	82.80	86.25	125.55	9.35	1.75
S6	53.05	56.80	97.75	5.85	1.75
MEAN	**75.23**	**78.65**	**111.61**	**6.30**	**1.65**
SD	**12.96**	**12.93**	**13.41**	**2.08**	**0.11**

Phase 2: Drive to Line-up Point, Patrol and Observation Post

SUBJECT NUMBER	TOTAL WEIGHT AFTER PATROL (KG)	WATER WEIGHT AFTER PATROL (KG)	WATER DRUNK DURING PATROL (L)	WATER WEIGHT AFTER REFILLING (KG)	TOTAL WEIGHT AFTER OP (KG)	WATER WEIGHT AFTER OP (KG)	WATER DRUNK AT OP (L)	WATER WEIGHT AFTER REFILLING (KG)
S1	124.80	6.65	1.05	6.65	124.15	6.40	0.25	6.40
S2	112.15	3.60	0.15	3.60	110.70	2.90	0.70	2.90
S3	122.10	4.45	0.00	4.50	121.20	3.20	1.30	3.20
S4	91.75	4.15	2.55	5.90	91.15	3.80	2.10	5.90
S5	123.25	8.65	0.70	6.45	121.55	6.45	0.00	6.45
S6	95.55	4.40	1.45	3.05	94.10	3.05	0.00	3.05
MEAN	**111.60**	**5.33**	**0.98**	**5.03**	**110.48**	**4.30**	**0.73**	**4.65**
SD	**14.64**	**1.93**	**0.95**	**1.53**	**14.60**	**1.67**	**0.84**	**1.77**

Phase 3: Second Patrol

SUBJECT NUMBER	TOTAL WEIGHT AFTER PATROL (KG)	WATER WEIGHT AFTER PATROL (KG)	WATER DRUNK DURING PATROL (L)
S1	120.35	4.80	1.60
S2	110.55	2.45	0.45
S3	120.65	2.75	0.45
S4	90.55	2.60	3.30
S5	119.95	4.40	2.05
S6	93.55	2.30	0.75
MEAN	**109.27**	**3.22**	**1.43**
SD	**13.90**	**1.09**	**1.12**

Phase 4: Return to RHQ (Taylor Barracks)

NO	PATROL ORDER (KG)	CLOTHED WEIGHT (KG)	NUDE WEIGHT (KG)	FINAL WATER (L)	WATER DRUNK FOURTH PHASE (L)	FINAL CRP (KG)	WEIGHT OF CRP EATEN (KG)	TOTAL URINE VOLUME (L)
S1	121.00	88.80	84.85	4.40	0.40	1.05	0.50	0.07
S2	117.95	86.60	82.90	1.80	0.65	0.95	0.60	0.23
S3	110.00	80.60	76.50	2.70	0.05	0.85	0.70	0.46
S4	89.75	70.10	66.95	1.45	1.15	1.55	0.20	2.03
S5	119.20	85.55	82.05	4.20	0.20	0.95	0.80	1.05
S6	92.75	56.85	52.55	1.30	1.00	1.20	0.55	0.31
MEAN	**108.44**	**78.08**	**74.30**	**2.64**	**0.58**	**1.09**	**0.56**	**0.69**
SD	**13.87**	**12.36**	**12.47**	**1.37**	**0.44**	**0.25**	**0.21**	**0.74**

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19. ABSTRACT

A study was conducted to investigate the physiological performance of soldiers undertaking long range reconnissance and surveillance activities in the Pilbara region, WA. The results indicated that soldiers experienced very low levels of heat strain during the transport and the setting up of the observation post phases. The heat strain increased to moderate levels while the subjects were conducting a route march in the afternoon. None of the thermal strain indicators (mean core temperature, average heart rate and average area weighted mean skin temperature) exceeded the level considered to indicate moderate heat strain by most civilian OH&S practitioners. The work load on the route march was approximately 50% of the peak metabolic rate, suggesting that this activity was sustainable provided that the environmental heat stress remained moderate. The sweating rate of the soldiers was generally low, with over 90% of the fluid loss attributable to evaporative cooling. There was also evidence that some soldiers experienced hypohydration while one subject appeared hyperhydrated. Based on the outcomes of the Soldier Combat Systems Enhancement Studies and the guidance from DOHSMAN, it is recommended that soldiers undertaking arduous activities should have a minimum fluid intake of 1.5 L.h-1 and that an hourly cycle of 30 min work/30 min rest should be introduced if the Wet Bulb Globe Temperature (WBGT) reaches or exceeds 280C. Caution must be exercised in interpreting the results as the weather conditions at the time of the study were influenced by a low pressure system. Consequently, the study was carried out under conditions far less stressful than normally experienced in this region. It is recommened that a repeat of the study is necessary to ascertain the true levels of heat strain soldiers would experience under typical hot and dry climatic conditions.

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